PELVIC ROTATION DYNAMICS OF ACCURACY ENHANCED, SUBMAXIMAL EFFORT INSTEP SOCCER KICKING

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The purpose of this study was to clarify the kinetic aspects of the pelvic rotation in accuracy enhanced, submaximal effort soccer instep kicking. Fifteen male soccer players conducted instep kicking in a maximal (MAX) effort and a submaximal (SUB) effort with an emphasis on accuracy. Kicking motions were recorded by a motion capture system with a force platform at 500 Hz. The counter-clockwise pelvic rotation decreased significantly in SUB. Also, the interaction torque on the support leg hip joint decreased significantly in SUB. A previous study reported that the interaction torque was the primary factor in producing pelvic rotation. Thus, controlled pelvic rotation seen in SUB is most likely due to a reduced interaction torque acting on the support leg hip joint. It can be considered that to restrain pelvic rotation is a strategy to slow down the foot swing velocity in accuracy enhanced, submaximal effort instep kicking.

KEY WORDS: control, accuracy, joint torque, interaction torque

INTRODUCTION: Instep kicking is one of the essential techniques among numerous types of the kick in soccer. Many previous studies turned the kicks into an object of motion analysis, and its kinetical nature has been revealed (Dorge, Anderson, Sorensen, & Simonsen, 2002; Nunome, Asai, Ikegami, & Sakurai, 2002; Nunome, Ikegami, Kozakai, Apriantono, & Sano, 2006; Putnam, 1991). However, most of the previous studies solely analysed the instep kicks or similar kicks with maximal effort.

During a soccer match, players make a pass and shoot using submaximal effort kicking so that they can control the ball speed and trajectory as intended. Several previous studies (Andersen & Dorge, 2011; Lees & Nolan, 2002; Teixeira, 1999) have investigated the kinematics of the kicking motion under accuracy enhanced conditions and informed that the ball and kicking leg speeds become significantly slower than those in speed enhanced conditions. Meanwhile, Lees and Nolan (2002) revealed that the speed of the approach run-up and the range of motions (ROMs) of the knee and hip joint on kicking leg and pelvic rotation were reduced under the accuracy enhanced, submaximal effort condition in comparison with the speed enhanced, maximal effort condition.

An instep kicking motion includes a proximal-distal sequential motion of the swing leg (Nunome et al., 2006; Putnam, 1991). Pelvic horizontal rotation is also generally seen in the sophisticated instep kicking style, and it has been characterised that the pelvic rotation precedes a proximal-to-distal sequence of segmental action of the swing limb (Inoue, Nunome, Sterzing, Shinkai, & Ikegami, 2014). These findings may imply that the pelvic rotation affects subsequent leg swing motion. In other words, there is a potential that soccer players control their pelvic rotational motion when they kick the ball in accuracy enhanced, submaximal effort condition. To the best of our knowledge, there is only one study that attmpted to analyse the kinetics of the pelvic rotation (Inoue et al., 2014). Their study revealed that the pelvic rotation was mainly induced by an interaction torque due to the ground reaction force acting to the support leg. However, the previous study only focused on the maximal effort instep kicking. Thus, no studies have ever examined the kinetic factors that drive the pelvic rotation in accuracy enhanced, submaximal effort instep kicking.

This study aimed to compare the joint and interaction torques acting on the pelvis between the maximal and submaximal effort of instep kicking. The purpose of present study was to clarify the kinetic aspects of the pelvic rotation in accuracy enhanced, submaximal effort soccer instep kicking.

METHODS: Fifteen male experienced collegiate soccer players (age: 20.9±0.5 years, height: 170.2±4.9 cm, weight: 67.9±7.6 kg) from a team in a local top collegiate league, volunteered

to participate in this study. All participants had a minimum of 10 years playing experience (14.1±1.9 years) and no injury at the time of testing. The experiment protocol was approval by the local ethics committee of a university and informed written consent was obtained from each participant before testing.
Participants performed two type of instep kicks of a stationary ball (FIFA approved size 5) toward the centre of an indoor soccer goal using their preferred leg (right leg). Participants were instructed to conduct the kicking trials in the two conditions which defined as follows: (1) kicking the ball as fast as possible namely maximal effort instep kicking; (2) kicking the ball as accurately as possible namely submaximal effort instep kicking. Hereafter, we refer to the conditions as MAX condition and SUB condition, respectively.
Kicking motions and ground reaction force (GRF) were captured by a 10-camera motion capture system (Vicon T20) with a force platform (Kistler) at 500 Hz. All participants appropriately warmed-up and performed familiarisation trials before data collection. They completed ten consecutive trials under the each condition in a random order so that successful shots (having a good ball impact and getting the central region of the goal) could be selected.
The foot and ball velocity were calculated using regression formula which derived by the time and displacement data just before or after ball impact (Nunome et al., 2006). The body's centre of gravity (CoG) was differentiated to calculate its velocity.
The legs were modelled as a linked segment model composed of the foot, shank, thigh, and pelvis segment (Nunome et al., 2002). The horizontal angular velocity of the pelvis segment was also computed as the rate of rotation about the pelvis yaw axis, which defined a normal vector to the plane formed by both hip joint centres and the midpoint of the posterior superior iliac spine. According to the procedure described by Inoue et al. (2014), we computed the torques acting on both legs to the pelvis: the reaction hip joint torque (muscle torque) and the torque due to the hip joint reaction force (interaction torque). All the four torques, i.e. muscle torque of the support leg (MTS), interaction torque of the support leg (ITS), muscle torque of the kicking leg (MTK), and interaction torque of the kicking leg (ITK), were decomposed into the pelvis yaw axis. Counter-clockwise rotation from the overhead view corresponded to the positive direction (+) for the angular velocity and torques. We also computed the range of motion (ROM) and angular impulses founded by integration of the angular velocity and torques during the support phase mentioned later.
All the angular velocity and torque data were smoothed using a fourth-order Butterworth low-pass filter with a cut-off frequency of 25 Hz. For the kicking leg side data, we used the procedure applied in the previous study (Nunome et al., 2006) to avoid ball impact artefact on foot motion. The period from the support leg touchdown to ball impact was normalised to 100%. The analysed portion was expanded to -50% using the same scaling factor for normalisation. The period from 0% to 100% was termed support phase.
Paired t-test was used for comparisons between MAX and SUB conditions. Statistical significance level was set at $p<0.05$.

RESULTS: Table 1 summarises the velocities of the ball, foot, and CoG at the average value (±SD). For all of the velocities, SUB condition showed a significantly lower value than MAX condition. Peak absolute GRF also showed significantly lower value in SUB condition (SUB: 1811.0±163.1 N, MAX: 2172.1±282.3 N; $p<0.001$).

Table 1. The average velocity (±SD) of the foot, ball and body's centre of gravity (CoG).

	SUB	MAX	p-value
Foot velocity (m/s)	14.6 (1.6) *	17.5 (0.9)	< 0.001
Ball velocity (m/s)	20.6 (3.0) *	26.2 (1.4)	< 0.001
CoG velocity at touchdown (m/s)	2.8 (0.3) *	3.1 (0.2)	< 0.001

*: Significantly defferent from MAX condition ($p < 0.05$)

Figure 1 shows the average curve (±SD) of the pelvic rotation angular velocity in both conditions. While its counter-clockwise rotation was clearly observed during the support phase in both conditions, the ROM of SUB condition was significantly smaller than that of MAX condition (SUB: 10.8±8.4 deg, MAX: 18.2±8.2 deg; $p<0.001$).

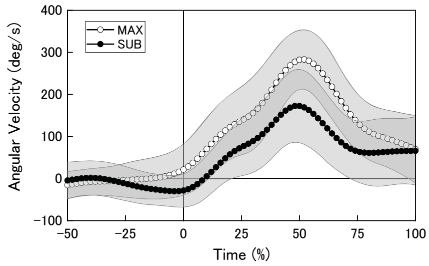

Figure 1. The average value (±SD) of the pelvic rotation angular velocity. Counter clockwise rotation (+).

Figure 2 shows the average curve (±SD) of MTS and ITS in both conditions. MTS in both conditions acted in the counter-clockwise direction across the touchdown and then began to generate the clockwise torque from the mid support phase. The angular impulse due to MTS showed a significant difference between the two conditions (SUB: 0.3±1.8 Nms, MAX: -1.3 ±2.2 Nms; $p<0.001$). ITS appeared to act on counter-clockwise direction from the touchdown in both conditions. The angular impulse due to ITS of the SUB condition was significantly smaller than that of MAX condition (SUB: 6.0±1.4 Nms, MAX: 6.5±1.4 Nms; $p<0.001$).

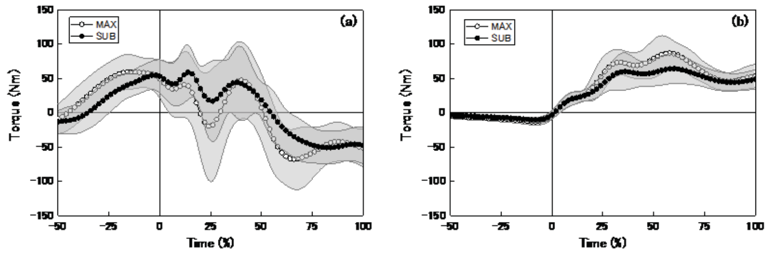

Figure 2. The average value (±SD) of MTS (a) and ITS (b). Counter-clockwise rotation (+).

Figure 3 shows the average curve (±SD) of MTK and ITK in both conditions. MTK and ITK acted in the clockwise direction first, and then began to exhibit the counter-clockwise torque from the mid support phase (ITK) or the final support phase (MTK). The angular impulse due to ITK of SUB condition was significantly smaller than that of MAX condition (SUB: 0.5±0.4 Nms, MAX: 0.9±0.4 Nms; $p<0.001$), whereas there was no significant difference for the angular impulse due to the MTK between SUB and MAX conditions (SUB: -5.6±1.6 Nms, MAX: -5.2±1.3 Nms; $p=0.09$).

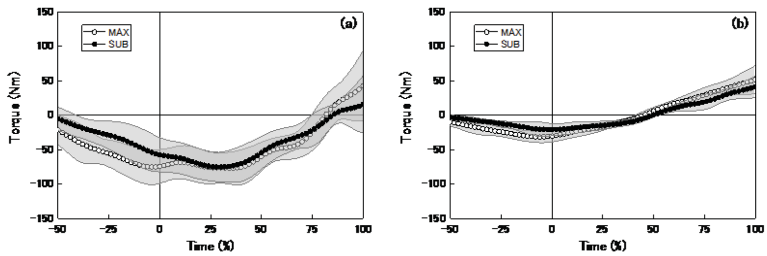

Figure 3. The average value (±SD) of MTK (a) and ITK (b). Counter-clockwise rotation (+).

DISCUSSION: The velocities of the ball, foot, and CoG were significantly reduced in SUB condition. These results agree with the findings reported by Lees and Nolan (2002) and confirm that the subjects have an intention to enhance accuracy, thereby conducting the kicking with submaximal effort.

The present study indicated that the ROM of the counter-clockwise pelvic rotation was significantly reduced when the subjects kick the ball in accuracy enhanced condition. This result agrees with the previous findings that soccer players displayed a smaller pelvic rotation when kicking the ball with an emphasis on accuracy (Lees and Nolan, 2002). It has been characterised that the pelvic rotation precedes a proximal-to-distal sequence of lower limb segmental action during kicking (Inoue et al. 2014). Therefore, it can be suggested that the reduced pelvic rotation observed in accuracy enhanced instep kicking, would have some impact on subsequent leg swing motion, thereby causing slower foot and ball velocity.

In the present study, we tried to demonstrate the mechanism how the pelvic rotation to be restrained in SUB condition from the changes of four torques (MTS, ITS, MTK, and ITK) acting on the pelvis. Inoue et al. (2014) reported that the interaction torque of the support leg hip joint (ITS) was the primary factor in producing pelvic rotation of maximal effort instep kicking and this torque exclusively attributed to GRF. Although ITS in both conditions showed a similar changing pattern which acted in the counter-clockwise direction during the support phase, the angular impulse of ITS decreased significantly in SUB condition. Besides, we observed that the approach speed of CoG and the GRF decreased significantly in SUB condition. These results suggest that soccer players tend to control the approach velocity when they required to kick the ball more accurately. The reduced approach velocity most likely induced the reduced GRF, thereby restraining the pelvic rotation through the interaction torque acting on the support leg hip joint.

MTS in both conditions also acted in the counter-clockwise direction during the early part of support phase. However, MTS had a considerable variability among the subjects (see Figure 2a). Hence, this torque would not make a decisive contribution to control the pelvic rotation during accuracy enhanced, submaximal effort instep kicking.

On the other hand, for torques on the kicking leg side (ITK and MTK), there were no notable differences. Thus, it can be assumed that these torques produced on the kicking leg side do not have a crucial role to restrain the pelvic rotation when kicking the ball accurately.

CONCLUSION: Soccer players most likely have a strategy to adjust approach run velocity thereby controlling pelvic rotation during accuracy enhanced, submaximal effort instep kicking. The slower approach run induced the reduced ground reaction force. The reduced ground reaction force likely explain the restrained action of the interaction torque on the support leg hip joint considered as the main drive of the pelvis rotation during kicking.

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